The Cybernetics Lab @ RWTH Aachen University:
4.0, Distributed AI and their Impact on Products, Processes and Interaction models

Meeting with Mitsubishi Electric Co. Ltd., Head Office and NRW.INVEST

October 5th, 2016 - Tokyo

Univ.-Prof. Dr. rer. nat. Sabina Jeschke
Cybernetics Lab IMA/ZLW & IfU
Faculty of Mechanical Engineering
RWTH Aachen University
I. Introduction
   - The Cybernetics Lab IMA/ZLW & IfU
   - Facts and data

II. The Philosophie of 4.0
   - The rise of AI... and its relation to 4.0
   - Entering the scene: intelligent self-learning systems

III. Intelligent systems at the cybernetics lab IMA/ZLW & IfU
   - From autonomous trucks and lot size 1...
   - ... to cognitive computing and multi agent systems

IV. A glimpse into modern AI
   - Data-driven methods: supervised and unsupervised learning
   - Trial-and-error driven methods: neuroevolution
   - Deep learning – a powerful tool for “both sides”
   - Shake it: AlphaGo

V. Summary and Outlook
The Multidisciplinary Cybernetics Lab IMA/ZLW & IfU

... Organisational Chart

 apl.-Prof. Dr. habil. Ingrid Isenhardt
 Deputy Head of Institute

 Prof. Dr. rer. nat. Sabina Jeschke
 Head of Institute

 Prof. Dr.-Ing. em. Klaus Henning
 Senior Advisor

 Dr. rer. nat. Frank Hees
 Vice Deputy Head of Institute

 IMA
 Institute of Information Management in Mechanical Engineering
 Prof. Dr.-Ing. Tobias Meisen
 Managing Director Junior Professorship

 ZLW
 Center for Learning and Knowledge Management
 Prof. Dr. phil. Anja Richert
 Managing Director Junior Professorship

 IfU
 Associated Institute for Management Cybernetics
 Dr. rer. nat. René Vossen
 Managing Director

 Traffic and Mobility
 Dipl.-Inform. Christian Kohlschein (temporary)

 Production Technology
 Dr.-Ing. Christian Büscher

 Cognitive Computing & eHealth
 Dipl.-Inform. Christian Kohlschein

 Innovation Research & Work Studies
 Stefan Schröder M. Sc.

 Knowledge Engineering
 Sebastian Stiehm M. Sc.

 Didactics in STEM Fields
 Valerie Stehling M. A.

 Agile Management & eHumanities
 Dr.-Ing. Christian Tummel

 Economic and Social Cybernetics
 Dr. phil. Kristina Lahl

 Engineering Cybernetics
 Dipl.-Wirt.-Ing. Sebastian Reuter

 Administration

 IT & Media Technology

 Public Relations

 Innovation Research & Work Studies

 Production Technology

 Cognitive Computing & eHealth

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 06.10.2016
 S. Jeschke
The Multidisciplinary Cybernetics Lab IMA/ZLW & IfU

... Data and Facts

... at the Faculty of Mechanical Engineering of the RWTH Aachen University

Cross-disciplinary teams work together on interdisciplinary projects

Team = ca. 215 employees

- ca. 65 scientists
  - 50 % from Engineering and Natural Sciences
  - 50 % from Humanities and Economic Sciences
  - Gender-Mix: ca. 50:50
  - Culture-Mix: ca. 90:10 (heavily under construction)

- ca. 20 employees for technical service and administration
- ca. 130 student workers

Financial structure in a nutshell

- ca. 85 % third-party funding
- ca. 6 million € annual turnover
Central terms in the field of intelligent distributed systems

The central elements of Cybernetics

- **Term**: "governance", to navigate
- **Born around 1940**
- **1948**: “Cybernetics or control and communication in the Animal and in the machine” (Norbert Wiener)
- **until 1953**: Macy-Conferences

**Feedbackloop**
Circular explanations for systems behavior, self-regulation (Forrester, Ashby)

**Autopoiesis**
System capacity to maintain and stabilize itself (Maturana, Varela)

**Decentralization**
Decentralized navigation, bottom up processes (Stafford Beer)

**Complex Systems**
Multi-component systems in complex interactions (Stafford Beer)

**Emergence**
Spontaneous new properties, swarm behavior (Wolfram, Gell-Mann)
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... leading to the 4th industrial (r)evolution...

**Breakthroughs - A new era of artificial intelligence**

**Communication technology**
bandwidth and computational power

**Embedded systems**
miniaturization

**Semantic technologies**
information integration

**Artificial intelligence**
behavior and decision support

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Systems of “human-like” complexity

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Watson 2011

Google Car 2012
... leading to the 4th industrial (r)evolution...

Breakthroughs - Everybody and everything is networked

**Communication technology**
bandwidth and computational power

**Embedded systems**
miniaturization

**Semantic technologies**
information integration

**Artificial intelligence**
behavior and decision support

- **Swarm Robotics**
- **Team Robotics**
- **Smart Factory**
- **Car2Infra-structure**
- **Smart Grid**

06.10.2016
S. Jeschke
The fourth industrial (r)evolution
“Information Revolution”

Everybody and everything is networked. - Big Data & Cyber-Physical Systems

“Internet of Things & Services, M2M or Cyber Physical Systems are much more than just buzzwords for the outlook of connecting 50 billions devices by 2015.”
Dr. Stefan Ferber, Bosch (2011)

Vision of Wireless Next Generation System (WiNGS) Lab at the University of Texas at San Antonio, Dr. Kelley

Weidmüller, Vission 2020 - Industrial Revolution 4.0
Intelligently networked, self-controlling manufacturing systems

“local“ to „global“
around 1750 to around 1900 to around 1970 to today

1st industrial revolution
Mechanical production systematically using the power of water and steam

Power revolution
Centralized electric power infrastructure; mass production by division of labor

Digital revolution
Digital computing and communication technology, enhancing systems’ intelligence

Information revolution
Everybody and everything is networked – networked information as a “huge brain”
... towards a networked world

And How do These Systems Work?

Communication technology
bandwidth and computational power

Embedded systems
miniaturization

Semantic technologies
information integration

?? Steering - Controlling ??

Towards intelligent and (partly-) autonomous systems AND systems of systems

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<td>Everybody and everything is networked – networked information as a “huge brain”</td>
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around 1750  
around 1900  
around 1970  
today
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From the history of autonomous vehicles

2009: Truck robot platoons – **distributed** intelligence

The KONVOI project (several institutes from RWTH & industry partners)

- 2005-2009
- automated / partly autonomous transportation e.g. by electronically coupling trucks to convoys
- several successful tests with trucks: Chauffeur, KONVOI, SARTRE (EU), Energy-ITS (Japan), ...

Adv. driver assistance system for trucks
- short distances between vehicles of approx. 10m at a velocity of 80 km/h
- Energy-ITS: 4m ! (2013)

KONVOI:
- Car2infrastructure components!
- Model of multi agent systems

expected improvements: beyond safety, reduction of fuel consumption and gained road space

Projects at IMA/ZLW & IfU
Network collaboration
Coupling manufacturing & logistics – towards lot size 1

Organization forms on demand – individualized by client - initialized by product

- Heterogenous player modeled as multi agent concept
- Models from biology and social sciences
- Basis on Autopoiesis & embodiment theory

Product agitates as “super-agent”:
- Plans production and transportation steps
- Requests service from agents
- Negotiates with other products for agent-resources

- Konvoi 2005-2009, RWTH with partners
- (partly) autonomous driving via convoys

Projects at IMA/ZLW & IfU
Dealing with complexity

Human machine interaction and cooperative robotics

Robots are no longer locked in work-cells but cooperate with each other and/or with humans

Robotics entering the scene as:

Cognitive computing is about „solving real problems“. Real problems are usually part of our real, physical world...

The enhancement of AI is strongly connected to the progress in robotics, coupled by the embodiment theory.
Advantage of decentralized control structures

Intralogistics goes mobile: The Festo Logistics League

Mobile transportation robots from flexible routing

Competencies:
- localization & navigation
- computer vision
- adaptive planning
- multi agent strategies
- sensory & hardware

Competitions robocup:
2012: 0 points in World Cup
2013: 4th in World Cup
2014: Winner of the GermanOpen
**2014: Winner of the World Cup**
**2015: Winner of the World Cup**
2016: Winner of the World Cup

Critical factors for success:
- Totally decentralized
- No ”hard coded components“
- Strong cooperation
- Re-planning during tasks

Projects at IMA/ZLW & IfU 2014 (ongoing)

http://www.carologistics.org/
Lend the robots a face
Into Service Robotics: The next step – the “Oscars”

Transform mobile robotic experiences into the field of service robotics

1. Investigating “new” human machine interfaces and interaction schemes
   - Simple, intuitive
   - Schematic eyes following you
   - “natural eyes behavior”: randomly looking around, showing interest by blinking, looking bored, ...

2. Investigating the “Uncanny Valley”: when features look almost, but not exactly, like natural beings, it causes a response of revulsion among the observers (Mori 1970)

3. Investigating diversity specific reactions (gender, age, culture) to artificial systems and in particular robots
Did you ever **yell** at your GPS, e.g. when it told you the equivalent of *“drive through that river ahead!”*? 😊

Well, WE do constantly. And so the story went on like this:

Motivation and goal: Transform the GPS into an intelligent co-driver, i.e. get it to adapt to your emotions!

Solution: A machine-learning based system architecture. Did it work? Often! Was it fun? Hell, yeah! 😊

**Ingredients in a nutshell**

- Primary source of emotion: driver speech
- Machine-learning algorithm: Support Vector Machine (SVM)
- Training database: talk show based corpus (lots of yelling)
- Test-bed: a driving simulator
- Test persons: old and young
And how it went on...

Integrative Production Technology for High-Wage Countries

DFG Excellence Cluster (and DFG GradKolleg “RampUp”)
IMA/ZLW & IfU in
1. Decentralized production planning
2. Self-optimizing socio-technical assembly systems
3. Virtual Production Intelligence
4. MAS in (Intra-)Logistics

Speaker: Christian Brecher
Outline

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Towards machine learning

Machines and Learning

Can machines learn?
Can they learn to predict future states and to do tasks optimized and in the right way? And if so, how can they do it?

→ This is what this talk is about!

How do machines learn?

A – Learning by observations and explanations
→ Data-driven learning

B – Learning by doing
→ Trial-and-error learning

! Let us take a look into a first example of data-driven learning!

Later...
Can we predict the result of an HPDC (high-pressure die casting) process – by using historical data? - **YES WE CAN!**

We extended the prediction model by integrating:
- mechanical vibration (using solid-borne sound sensors)
- weather data.

**Acoustic measurements**
Fourier transformation & feature extraction

**Extended model**
k-nearest clustering and random forest tree

**Weather data**
Temporal correlation of weather (and circumstances)
Data-driven learning - unsupervised

Unsupervised Learning “Down-to-Earth”

Finding hidden relations in our data, we were not aware of, e.g.
understanding failures or bad quality of products and processes

![Image showing industrial domain expert and data mining expert working together]

... in cooperation with

Data about chemical compositions of steel (identified as low quality - example)

Searching for hidden relations in data by applying subgroup mining

<table>
<thead>
<tr>
<th>Steel No.</th>
<th>Chemical Composition (%)</th>
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<tbody>
<tr>
<td></td>
<td>Fe</td>
</tr>
<tr>
<td>2018</td>
<td>92%</td>
</tr>
<tr>
<td>2019</td>
<td>80%</td>
</tr>
<tr>
<td>2020</td>
<td>70%</td>
</tr>
<tr>
<td>2021</td>
<td>60%</td>
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- Sulfur (S) > 0.04% and heat treatment ➔ fragile structure
- Phosphorus (P) > 0.04% ➔ reduced plasticity
- Chrome (Cr) > 16%, Molybdenum (Mo) > 13%, Nickel (Ni) > 56% ➔ no findings
- ...

[IfU, IMA, ZLW]
Learning by doing – reinforcement learning

The Next Step: Using Rewards to Learn Actions

Remember Mario: What if the machine could learn, how to solve a level? Why not use a some kind of intelligent trial-and-error?

Reinforcement learning (R-learning)
is inspired by behaviorist psychology – maximizing the expected return by applying a sequence of actions at a current state.

One kind of Intelligent Trial-and-Error:
- Neuroevolution of augmenting topologies (NEAT) [Stanley, 2002]
  - Genetic algorithms on top of neural networks
  - At each state the system decides what action to take
  - Actions are rewarded if Mario does not die in return
  - Level progress by evolving neural networks

Human factor is “very small”
- reduced to very general, mainly formal specifications of the neural network...
- However, human still influences the underlying representation model
Deep learning

Where the Story Goes: AlphaGo

Go originated in China more than 2,500 years ago. Confucius wrote about it. As simple as the rules are, Go is a game of profound complexity. This complexity is what makes Go hard for computers to play, and an irresistible challenge to artificial intelligence (AI) researchers. [adapted from Hassabis, 2016]

The problem: \(2.57 \times 10^{210}\) possible positions - that is more than the number of atoms in the universe, and more than a googol times \((10^{100})\) larger than chess.

Bringing it all together!

- **Training set**
  - 30 million moves recorded from games played by humans experts

- **Creating deep neural networks**
  - 12 network layers with millions of neuron-like connections

- **Predicting the human move**
  - (57% of time)

**Learning non-human strategies**

AlphaGo designed by Google DeepMind, played against itself in thousands of games and evolved its neural networks; Monte Carlo tree search

**March 2016:**

Beating Lee Se-dol (World Champion)

AlphaGo won 4 games to 1. (5 years before time)

Achieving one of the grand challenges of AI
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Summary
... in Four Steps!

4.0: The Revolution of a distributed artificial intelligence

We are right in the middle of a 4th Industrial Revolution.

Google (Amazon, Facebook, ...) ... is coming!

The break-through into the real world systems

Big Data ... is about smart big and broad data

Systems and technology are changing rapidly. Technical systems become intelligent and “talkative”.

The main cloud behind big data is not only the algorithmic progress but the concept of using ALL available data for prediction, even if their context and connection is not clear from the start.

If we do not want to let Google and co. run this show as well, we better start embracing AI NOW!

So far, the majority of the impressive AI algorithms work within the “virtual world”. But their power is not at all restricted to “playful environments”...
Thank you!

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